Investigating Genetic algorithm for the RCS chain parameters

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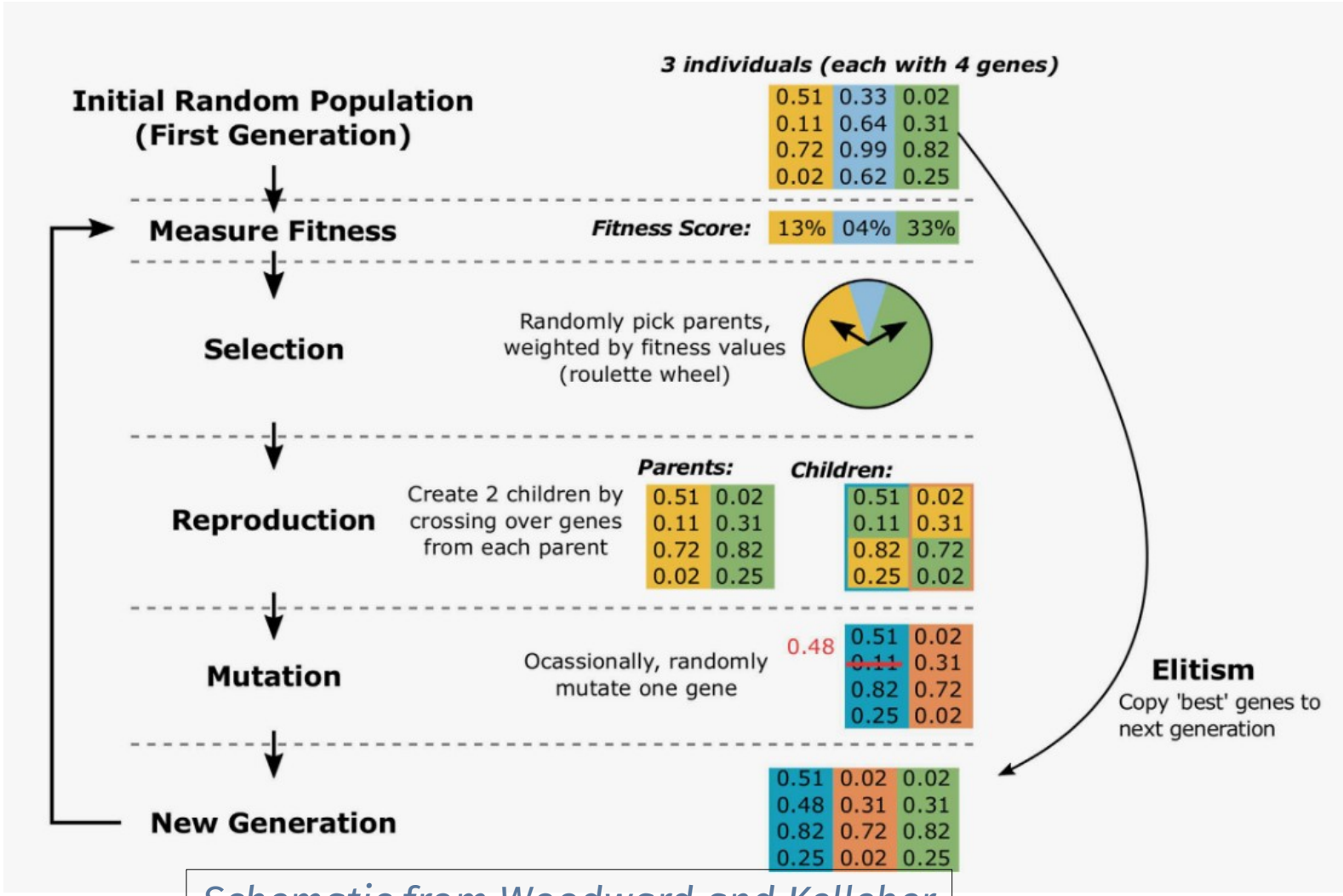


Schematic from Woodward and Kelleher

Function to optimize

- Start by expressing the function to optimize. Here we will try to minimize the energy gain per turn required in each RCS.
  - The energy gain per turn determines the total RF voltage needed for the accelerator

$$\texttt{minimize} \quad E_{turn,i} = \frac{2\pi R_i}{c_0} \frac{\gamma_{ext,i} - \gamma_{inj,i}}{\tau_{acc,i}} = \frac{2\pi R_i}{c_0} \frac{\gamma_{inj,i+1} - \gamma_{inj,i}}{\tau_{acc,i}} \qquad i \in (1,2,3,4)$$

- The variables used in the problem are the the injection gamma $\gamma_{inj,i}$. Here i=5 represents the injection energy in the collider, so the extraction energy of the RCS 4
- The other variables used are the acceleration time τ in each RCS

Function to optimize

- We should also ensure that the transmission through the 4 RCS remains above a selected target

$$N_4 = N_0 \left(\frac{\gamma_{inj,2}}{\gamma_{inj,1}}\right)^{-\frac{1}{\tau_\mu}\frac{\tau_{acc,1}}{\gamma_{inj,2}-\gamma_{inj,1}}} \left(\frac{\gamma_{inj,3}}{\gamma_{inj,2}}\right)^{-\frac{1}{\tau_\mu}\frac{\tau_{acc,2}}{\gamma_{inj,3}-\gamma_{inj,2}}} \left(\frac{\gamma_{inj,4}}{\gamma_{inj,3}}\right)^{-\frac{1}{\tau_\mu}\frac{\tau_{acc,3}}{\gamma_{inj,4}-\gamma_{inj,3}}} \left(\frac{\gamma_{inj,5}}{\gamma_{inj,4}}\right)^{-\frac{1}{\tau_\mu}\frac{\tau_{acc,4}}{\gamma_{inj,5}-\gamma_{inj,4}}}$$

$$\texttt{ensure} \quad \frac{N_4}{N_0} \geq N_{target}$$

Function to optimize

- The total magnet length should also remain below the packing factor

$$L_{NC,1} = 3.3356 \cdot 2\pi \frac{\sqrt{\gamma_{inj,2}^2 - 1} m_\mu [GeV]}{B_{NC}}$$

$$L_{NC+SC,i} = 3.3356 \cdot 2\pi m_\mu [GeV] \cdot \left(\frac{\sqrt{\gamma_{inj,i+1}^2 - 1} + \sqrt{\gamma_{inj,i}^2 - 1}}{2B_{SC}} + \frac{\sqrt{\gamma_{inj,i+1}^2 - 1} - \sqrt{\gamma_{inj,i}^2 - 1}}{2B_{NC}} \right)$$

$$\begin{aligned} L_{NC,1} &\leq \eta_1 2\pi R_1 \\ L_{NC+SC,2} &= L_{NC,1} \\ L_{NC+SC,3} &\leq \eta_3 2\pi R_3 \\ L_{NC+SC,4} &\leq \eta_4 2\pi R_4 \end{aligned}$$

Fixed parameters

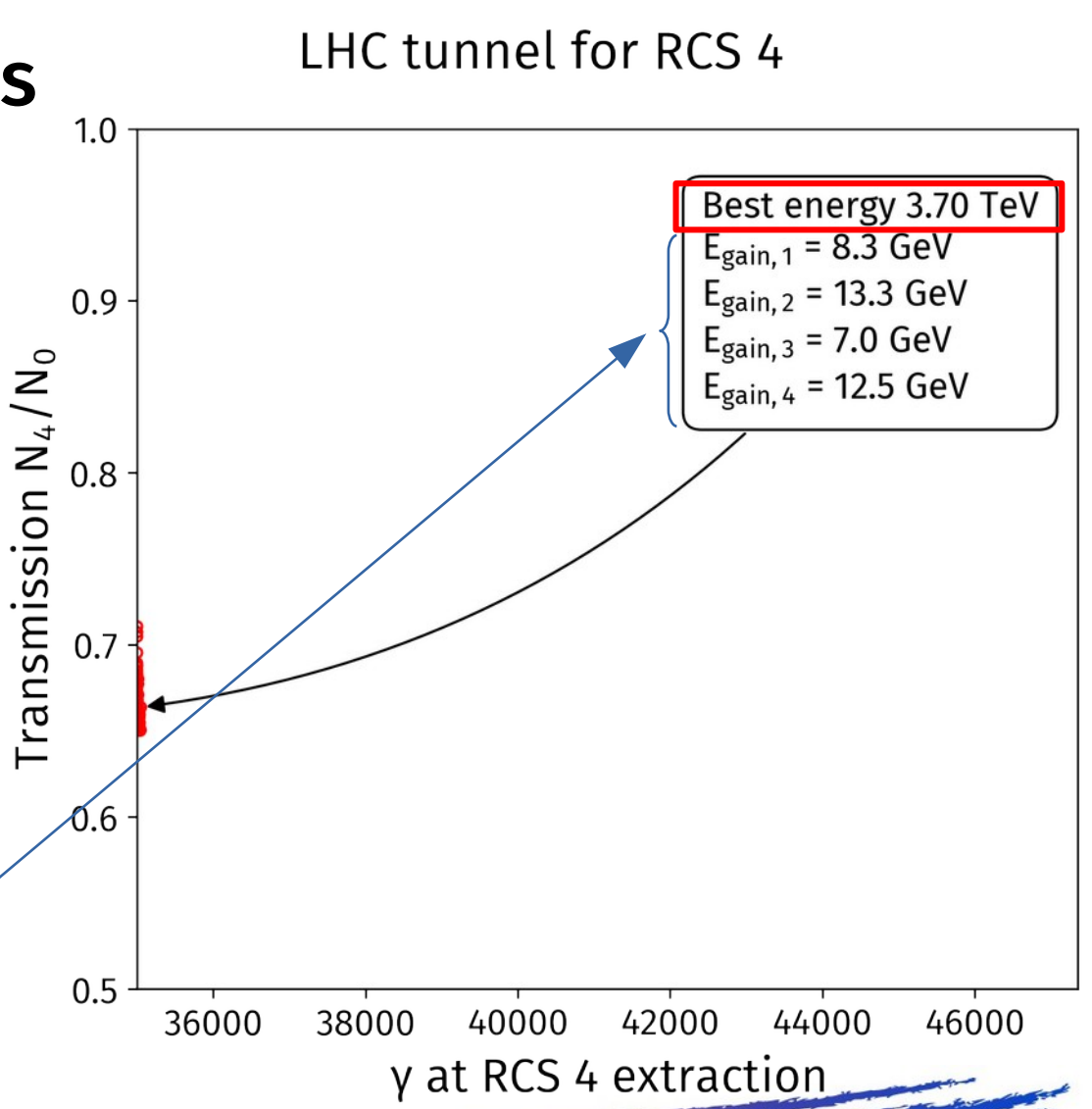
- We also need to provide some boundaries for the variables
- For the first test, try for fit the RCS 4 in the LHC tunnel (27 km)

Variable	Lower boundary	Upper boundary
$\gamma_{inj,2}$ ($E_{inj,2}$ [TeV])	1000 (0.106)	4500 (0.476)
$\gamma_{inj,3}$ ($E_{inj,3}$ [TeV])	4501 (0.476)	10000 (1.06)
$\gamma_{inj,4}$ ($E_{inj,4}$ [TeV])	10001 (1.06)	30000 (3.17)
$\gamma_{inj,5}$ ($E_{inj,5}$ [TeV])	35001 (3.70)	47350 (5.0)
τ_1 [ms]	0.3	3
τ_2 [ms]	0.3	3
τ_3 [ms]	0.8	8
τ_4 [ms]	1.0	12

Parameter	Value
RCS 1 circumference [m]	5990
RCS 2 circumference [m]	5990
RCS 3 circumference [m]	10000
RCS 4 circumference [m]	27000
Normal-conducting magnet maximum field [T]	1.8
Super-conducting magnet maximum field [T]	10
Lorentz gamma factor at injection in RCS 1	597
Total transmission N_4/N_0	≥ 0.65
RCS 1 packing factor	< 0.61
RCS 3 packing factor	< 0.63
RCS 4 packing factor	< 0.70

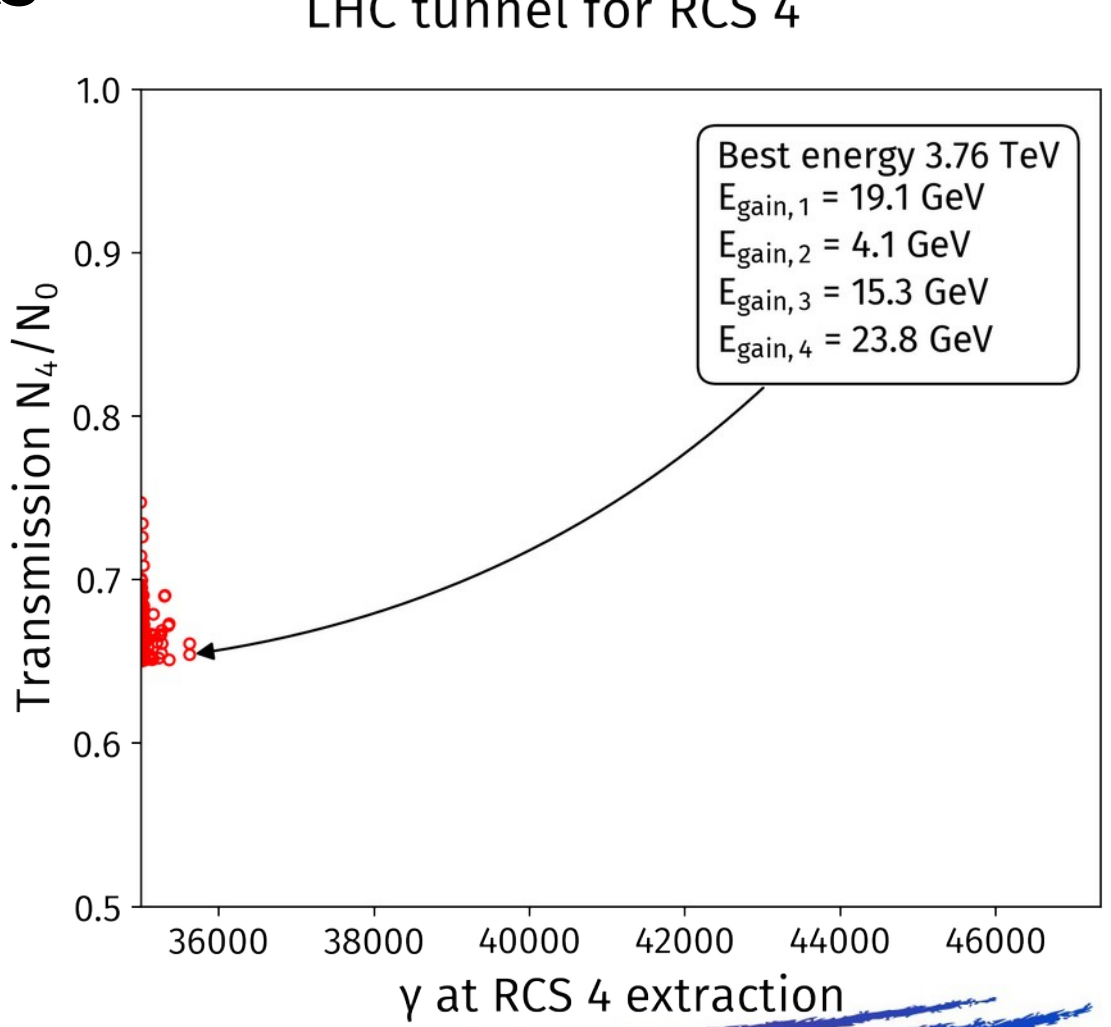
Optimization results

- Genetic Algorithm parameters
  - Population: 200
  - Generations: 1000
  - Children: 20
- For the first test, try for fit the RCS 4 in the LHC tunnel (27 km)
- Show the energy gain per turn required in each RCS



Optimization results

- Try for fit the RCS 4 in the LHC tunnel (27 km) and the RCS 1 and RCS 2 in the SPS tunnel (7 km)



Optimization results

- Try for fit the RCS 4 in the LHC tunnel (27 km), the RCS 1 and RCS 2 in the SPS tunnel (7 km)
- Now the dipole magnet fields for the RCS 4 are increased
  - 16 T for the SC magnets
  - 2.0 T for the NC magnets
- The packing factor for RCS 4 is increased to 0.7